GPS Precision Monitoring of Geologic Hazards

USTTI Seminar: Global Positioning System Applications for Disaster Management and Societal Benefits

Larry Hothem
U.S. Geological Survey
November 08, 2013
Acknowledgement

David Applegate, Ph.D.
- Associate Director for Natural Hazards, USGS, Reston, VA
- Email: Applegate@usgs.gov, +1-703-648-6600
- Website: http://www.usgs.gov/natural_hazards/

and

Kenneth W. Hudnut, Ph.D.
- Geophysicist, Earthquake Science Center, USGS, Pasadena, CA
- Email: Hudnut@usgs.gov, +1-626-583-7232
- Website: http://profile.usgs.gov/hudnut
Facing Tomorrow’s Challenges – USGS Science in the Decade 2007-2017

- Understanding Ecosystems and Predicting Ecosystem Change
- Climate Variability and Change
- Energy and Minerals for America’s Future
- A National Hazards, Risk, and Resilience Assessment Program
- The Role of Environment and Wildlife in Human Health
- A Water Census of the United States
Contents

Identifies four primary goals:
1. Enhanced Observations
2. Fundamental Understanding of Hazards and Impacts
3. Improved Assessment Products and Services
4. Effective Situational Awareness

A Vision of the Future
Opportunities and Challenges
Planning and Interconnections Across the USGS Mission Areas
USGS hazard roles and responsibilities

- Delegated federal responsibility to provide notifications and warnings for earthquakes, volcanic eruptions, and landslides.
- Seismic networks support NOAA’s tsunami warnings.
- Streamgages and storm surge monitors support NOAA’s flood and severe weather (including hurricane) warnings.
- Geomagnetic observatories support NOAA and AFWA geomagnetic storm forecasts.
- USGS has key role in tracking chemical and biological threats, in particular zoonotic diseases.
- Geospatial information supports response operations for wildfire and many other disasters.
Natural Hazards Mission Area programs

Earthquake Hazards

Coastal & Marine Geology

Global Seismographic Network

Volcano Hazards

Geomagnetism

Landslide Hazards
GPS provides precise positions of airborne sensors so that highly accurate base geospatial data products such as high resolution terrain (elevation) data and orthorectified imagery can be produced efficiently.

Highly accurate terrain elevation data is replacing older, lower resolution data.

Example of high resolution orthorectified imagery acquired in partnership with other Fed, state, and local agencies.
Accurate Lidar mapping is highly relevant to several data layers of The National Map.
LiDAR differencing: El Major – Cucapah M7.2 earthquake

GPS enables ultra-high-precision geo-ref for fault mapping using repeat-pass imagery
- LiDAR
- 3D stereo
The USGS role in the National Earthquake Hazard Reduction Program partnership

- Provide earthquake monitoring and notifications,
- Assess seismic hazards,
- Conduct targeted research needed to reduce the risk from earthquake hazards nationwide, and
- Work with NEHRP agencies and many other partners to support public awareness of earthquake hazards and impacts.
Earthquakes are a national hazard

USGS National Seismic Hazard Map

Notable earthquakes in past decade

M5.6  M5.3  M5.6  M5.3  M5.6

M6.8  M5.6  M5.3  M5.4  M5.8  M7.2  M6.0  M7.2

M6.5  M6.0  M6.6  M7.9

M6.7  M5.3

months
A network of GPS/GNSS stations measures plate tectonic motions to an accuracy of better than 1 mm/yr.

We can see whether the motion is ‘slow and steady,’ or perhaps more interestingly, it may sometimes accelerate or decelerate.
Plate Boundary Observatory

San Andreas plan

GNSS station clusters along San Andreas fault, especially along transitions from creeping to locked sections
Cajon Pass I-15 Fault Crossing

A real-time GNSS array

Detailed terrain profile from before and after imaging for rapid assessment of damage to lifeline infrastructure
Virginia Earthquake of August 23, 2011

Largest earthquake in Virginia in 114 years

Centered in low-population area between Richmond and Charlottesville

No fatalities. Estimated Damages >$100M

Felt from Florida to Maine to Missouri (>140,000 reports)

Caused evacuations across Washington DC metropolitan area, and damage to historic structures.
The August earthquake struck in a recognized zone of elevated hazard.

From Tarr & Wheeler, 2004
Continuous Operating Reference Stations (CORS)

Magnitude 5.8 Virginia Earthquake, August 23, 2011
March 11, 2011
Japan earthquake

Initial GPS results from GSI showed 2.6 meters shift; later results gave maximum GPS offset of 4.034 m (13.2 feet)

Data were openly available and other groups quickly confirmed these results and made movies of the displacements to help visualize the information

Since 1990, US advised Japan on construction of continuously-operating GPS stations (like ones we built in Southern California). They built a network of over 1000 GPS stations called GEONET.

Post-seismic: re-adjustments will go on for years, GPS is the best way to examine it
Vertical Displacements

Difference between estimated positions of GEONET stations at 05:00 and 06:30 UTC on March 11, 2011

Solutions by JPL and Caltech.

GPS 1 Hz data in RINEX format provided by the Geospatial Information Authority (GSI) of Japan.
Horizontal Displacements

Difference between estimated positions of GEONET stations at 05:00 and 06:30 UTC, March 11, 2011.

Bars at end of vector show 95% error estimate.

Solutions by JPL and Caltech.

GPS 1 Hz data in RINEX format provided by the Geospatial Information Authority (GSI) of Japan.
• Japanese early warning systems

Issued at 14:49 JST, 11 March 2011

Automatic earthquake warning triggered by computer

Japan Meteorological Agency initial tsunami warning

Notes
- Major Tsunami: Tsunami height is estimated to be 3 meters or more
- Tsunami: Tsunami height is estimated to be up to 2 meters

Tsunami Advisory
- Tsunami height is estimated to be about 0.5 meter
- Epicenter
Earthquake early warning – getting ahead of strong ground shaking

USGS/CISN Phase I (2007-2009) cooperative agreement supported algorithm testing

Phase II (2010-2012) supports prototype development and identifies test users

ARRA funding used to reduce datalogger delays

EEW requirements:
-- rapid earthquake detection
-- early magnitude estimation
-- ground shaking prediction
-- robust monitoring networks
-- well-defined user community
GPS & accelerometer arrays are being explored as part of a fully operational earthquake early warning system
- There are 169 potentially active US volcanoes
- USGS operates 5 volcano observatories in partnership with universities, state and other Federal agencies.
- USGS/USAID Volcano Disaster Assistance Team works globally
USGS volcano observatories combine an array of real-time data streams to interpret behavior and forecast eruptions.

- Gas cloud from satellite UV sensor
- AVO operations room
- Satellite surveillance for hotspots and ash
- Volcano deformation from radar satellites
- Volcano deformation from GPS
- Eruption onset from seismic network
- Magma chamber location from seismic tomography
GPS uses by USGS Volcano Hazards Program

- Key component of volcano monitoring for flank movements and lava dome growth
- Integral part of National Volcano Early Warning System plan for monitoring modernization and expansion
- Over 300 continuous GPS units are currently in use by USGS volcano observatories (nearly all of these are telemetered precise dual-frequency GPS stations; many are Plate Boundary Observatory stations operated by UNAVCO with NSF funding)
USGS uses precise GPS for eruption monitoring

**Motions of volcanoes’ flanks**
- Flank motions indicate the arrival of new magma.
- GPS is used to monitor changes in activity.

**Dome growth**
- Growth of volcanic domes can be monitored using GPS technology.
National Volcano Early Warning System (NVIEWS): Closing the monitoring gap

Based on systematic threat ranking of 169 U.S. Volcanoes

NVIEWS Goals:

• Robust real-time monitoring of the most threatening volcanoes.
• 24/7 Volcano Watch Office.
• Support for collaborative research and communication projects with State, Local and Academic partners.

Authorization bill pending before Senate Energy and Natural Resources Committee

<table>
<thead>
<tr>
<th>NVEWS TARGETS</th>
<th>MONITORING GAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilauea, HI</td>
<td>1 ERUPTION</td>
</tr>
<tr>
<td>St. Helens, WA</td>
<td>1 ERUPTION</td>
</tr>
<tr>
<td>Rainier, WA</td>
<td>3</td>
</tr>
<tr>
<td>Hood, OR</td>
<td>3</td>
</tr>
<tr>
<td>Shasta, CA</td>
<td>3</td>
</tr>
<tr>
<td>South Sister, OR</td>
<td>3</td>
</tr>
<tr>
<td>Lassen, CA</td>
<td>3</td>
</tr>
<tr>
<td>Mauna Loa, HI</td>
<td>2</td>
</tr>
<tr>
<td>Redoubt, AK</td>
<td>2</td>
</tr>
<tr>
<td>Makushin, AK</td>
<td>2</td>
</tr>
<tr>
<td>Glacier Peak, WA</td>
<td>4</td>
</tr>
<tr>
<td>Newberry Volcano, OR</td>
<td>3</td>
</tr>
<tr>
<td>Augustine, AK</td>
<td>2</td>
</tr>
<tr>
<td>Crater Lake, OR</td>
<td>4</td>
</tr>
<tr>
<td>Inyo Craters., CA</td>
<td>3</td>
</tr>
<tr>
<td>Adams, WA,</td>
<td>2</td>
</tr>
</tbody>
</table>
• GPS used for Streamgaging

• 9,000 USGS streamgages and water-quality monitoring sites use GPS timing for satellite communications
USGS WaterAlert

Text message or e-mail customized alerts

http://water.usgs.gov/wateralert/
GPS/GNSS for hazards management

• GPS/GNSS is an essential enabling technology for the mapping and precise monitoring needed to accomplish science missions in support of hazard warnings.

• In the aftermath of a significant disaster event, GPS/GNSS is critical in support of new mapping and geopositioning incident features - essential in support of immediate response (e.g., support Urban Search & Rescue) as well as for long-term recovery (e.g., organizing debris removal).
Questions?